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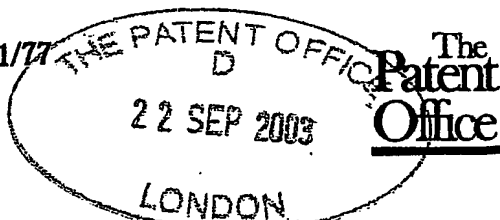
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Patents ADP number *(if you know it)*

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0864218300|

4. Title of the invention

CLADDING

5. Name of your agent *(if you have one)*

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**ABLETT & STEBBING
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W1U 6FQ**

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Date

ABLETT & STEBBING   **22 September 2003**

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CLADDING

This invention concerns a modular breathing wall cladding panel for commercial buildings and office blocks in polluted urban environments. Such panels enable the building envelope to act as an efficient heat exchanger, with reductions in operational energy achieved by using conduction heat loss to pre-heat ventilation air. The panels also act as highly efficient, maintenance-free filters of airborne particulates down to sub-micron scale for the life of the building, with similar filtration performance anticipated for biological and chemical filtration.

The result is a revolution in building technology that couples the external and built environments to save energy *and* provide clean ventilation air, filtered to HEPA levels, to occupants 24 hours a day, 365 days a year for life. Instead of adding pollution, it is possible for buildings in future to clean-up their surrounding urban environments.

1.0 Introduction

Up to 70% of EU primary energy, as opposed to 40% currently, will be imported by 2028.   The principal importers will be the Middle East, West Africa and the former states of the Soviet Union. This is less than ideal for energy security. Measures to reduce energy usage not adverse to continued growth, also needed if Kyoto commitments are to be met, are thus urgently required.

These are the drivers for the current emphasis on sustainable development, where less reliance on fossil fuels is being promoted in many countries to meet strict energy quotas and emission requirements. The construction industry clearly has a key role to play, since 50% of primary energy used in the developing world is associated with buildings, either through embodied or operational energy. This is one reason why passive strategies to provide ventilation air in buildings are becoming popular again with architects and developers.   The biggest barrier to success, however, relates to the quality of air delivered to the building, particularly in polluted urban environments. Although the background air quality in the UK over the past 20 years has seen remarkable reductions in PM10 content (i.e., the suspended particulate matter in the air below 10 microns)   air quality continues to decline in certain areas.

Breathing walls incorporating dynamic insulation, in which fresh ventilation air is drawn into the building using either active or passive depressurisation, offer an attractive alternative that brings us close to the natural ventilation ideal. The demonstrable benefits include enhanced energy efficiency through reduction of the building's dynamic U-value, the ability to deliver above average indoor ventilation rates without the penalty of increased energy usage, controllability of airflow into the building, and greatly reduced reliance on complex, expensive, high-maintenance HVAC plant.   In addition, breathing walls can filter out 99.9+ % of all airborne
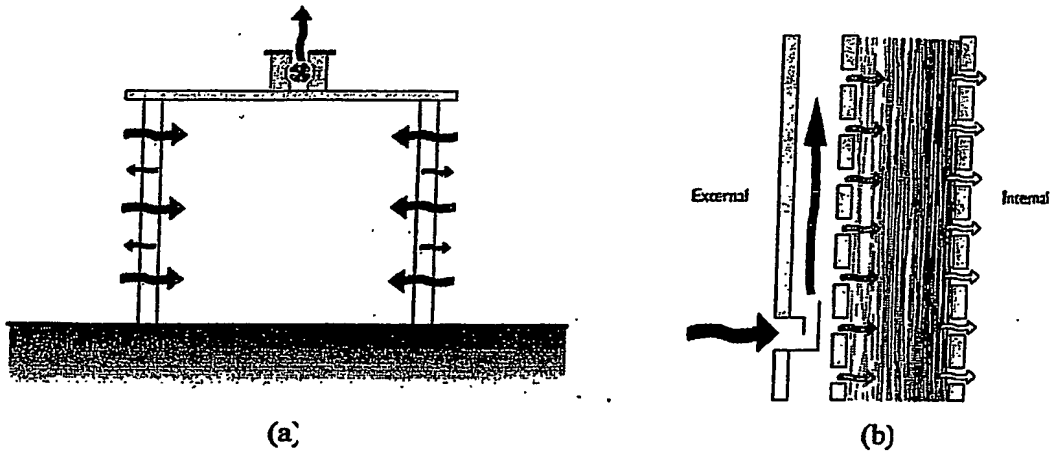
particulate, gaseous and other pollutants from the incoming ventilation air of as part of safe, maintenance-free system that lasts the lifetime of a building. This not only ensures that building occupants are protected at all time against the harmful effects of airborne pollution, but that such buildings will actually clean up the outdoor environment in which they are located. The breathing wall thus, in addition to it's other benefits, encapsulates an effective urban cleanup technology capable of reversing, at scale, the hazards of air pollution in cities across the world.

In developing the breathing wall technology to the stage where it can be practically and economically deployed in new build and retrofit building projects, the authors have investigated the use of fibre-based dynamic insulation media and it's performance evaluation in practice. A theoretical filtration model for fibre-based dynamic insulation media has been developed and is being validated in field trials using purpose-built test rigs.

They have also developed an innovative support, packaging and air distribution system for fibre-based media that in CFD simulation has been shown to facilitate uniform airflow across a large area of dynamic insulation - i.e., a breathing wall. The system also enables effective edge sealing of the media to eliminate unwanted leakage, allows pre-fabrication of a range of modular breathing wall cladding panels, and permits the generic replacement of conventional insulation in most retrofit installations. The cumulative findings from this research are reported in the present paper, and design of the world's first dynamically insulated office building is very briefly outlined. The challenge is to achieve all the aforementioned benefits of breathing wall technology whilst ensuring compliance with all statutory building regulations and architectural best practice.

1.1 Heat and Mass Transfer in Dynamic Insulation

As cool ventilation air is drawn into a warm building through the breathing wall, air flows inwards in the opposite direction to the heat being conducted outwards as shown in the figure below. The *contra-flow* of mass versus heat fluxes results in the cool air picking up heat that would normally be lost through conduction, effectively yielding a reduction in the dynamic U-value of the wall and higher overall insulation efficiency.

External   Internal

(a)   (b)

Figure 1.1 Heat and mass flows in (a) breathing building, and (b) breathing wall

The physics of heat and mass transfer through a dynamically insulated wall have been fully detailed in our earlier papers [5 - 7]. One can incorporate the dynamic U-value into an energy and airflow balance for the whole building to estimate the overall energy savings. This analysis, which can be carried out on a spreadsheet is ideal for the conceptual design of buildings. The dynamic U-value U_d for a multi-layer envelope can readily be calculated from the total thermal resistance of the wall R_s and the air flow through the wall v :

$$U_d = \frac{v \rho_a c_a}{R_s \left(\exp(v \rho_a c_a R_s) - 1 \right)}$$

(1)

Where ρ_a and c_a are the density and specific heat capacity of air.

To illustrate the effect of airflow rate through a breathing wall, consider a 200 mm thick layer of wet-blown cellulose insulation with a static (i.e., in the absence of airflow, or $v = 0$) U-value of $U_s = 0.168$ W/m^{2}K. At an arbitrarily very small airflow velocity of 0.000278 m/s (1 m/hr) the dynamic U-value for this insulation falls to U_d = 0.058 W/ m^{2}K, or $0.33 U_s$. At a more realistic (for breathing buildings) airflow velocity of 0.00278 m/s (10 m/hr) the dynamic U-value falls further to 1.7 E-8 W/ m^{2}K - i.e., it becomes effectively zero. A significantly thinner 40 mm thick layer of insulation would under similar conditions yield a dynamic U-value U_d = 0.13 W/ m^{2}K.

Similar energy savings with dynamic insulation also occur when warm outside air is drawn into a cool building in hot summer months, though in this case the heat and mass flows are in the same direction. As the warm air flows inwards it loses some of it's heat to the breathing wall, effectively reducing the temperature gradient between the ambient outdoor and the outward-facing wall surface, and therefore the U-value of the wall. The co-flow cooling behaviour of dynamic insulation is described in a similar manner to contra-flow heating behaviour, where the first reduces the cooling load and the latter reduces the heating load required for optimum indoor conditions. This dual functionality of dynamic insulation means that breathing buildings can continue to function optimally irrespective of seasonal, diurnal, or any other cyclical variation in ambient conditions. Only cooling in hot-humid conditions presents condensation problems, but these too may be resolved by the application of active or passive dehumidification methods.

1.2 PM$_{10}$ Filtration in Dynamic Insulation

Common air filtration media include membranes, foam-type cellular materials, pulps, and fibres. The latter represent an attractive choice for use in dynamically insulated

buildings due to their excellent performance in the $PM_{2.5}$ – PM_{10} range at low flow velocity, wide availability, utility, low cost, and prevalence. Our earlier investigations reveal that potentially suitable natural and man-made fibre-types and products already exist and are used as conventional insulation media.

In order to evaluate the filtration performance of breathing wall panels, a 1-D, multi-layer particle filtration model has been developed and outlined. This model has been further developed to investigate the filtration performance of a conventional, fibre-based insulation material (Glasswool) in filtering PM_{10}, and to address the following questions:

(a) What is the efficiency of filtration from a commercial insulation layer under conditions determined by dynamic insulation?

(b) What is the lifetime of the insulation layer - i.e., when, over time, will it become clogged?

A single-fibre model, was used to derive efficiency. This was coupled with an iterative representation of clogging in fibrous filters, The model will be calibrated using data from experimental tests and field trials, to account for 3D effects, etc., to be reported in due course.

The single fibre model:

The single-fibre model estimates the clean filter removal efficiency E, prior to particle deposition, using an expression of the form in Eq.(2) below:

$$E = 1 - \exp\left\{-\frac{4\alpha\eta Z}{(1-\alpha)d_f\pi}\right\}$$

(2)

Where α is the fibre density (packing fraction), d_f the fibre diameter, and Z the insulation layer thickness. η, the collection efficiency, is the sum of the collection

efficiencies ascribed to three different collection mechanisms, namely Brownian motion or diffusion (η_d), inertial deposition (η_{in}) and impaction (η_{im}). For clean fibres, this parameter is obtained as:

$$\eta = \eta_d + \eta_{in} + \eta_{im} \tag{3}$$

The above applies to filtration efficiency through a uniform layer of dynamic insulation, but has been extended to enable the study of multi-layer depth filtration, since the latter is necessary to avoid premature clogging and achieve longevity. The corresponding expressions for multi-layer filtration efficiency are of the form [12]:

$$E_{f,J,J_{l+k}} = 1 - \exp\left(\frac{-4 \cdot \alpha \cdot \eta_{f,J} \cdot Z_J}{\pi \cdot \left(1 - \alpha - \alpha_{p,J,J_{l+k}}\right)d_f}\right) \cdot \tag{4}$$

$$\eta_{f,J,J_{l+k}} = \eta_{f,J,d,J} + \eta_{f,J,in,J} + \eta_{f,J,im,J} = \eta_{f,J,J} \tag{5}$$

Where $\eta_{f,J,J}$ is the time-invariant single-fibre collection efficiency for layer J, and $\left(1 - \alpha - \alpha_{p,J,J_{l+k}}\right)$ is the permeability of the layer.

Dendrite formation and clogging model:

In a loaded fibre filter the internal structure changes over time, as branch-like dendrites form through the agglomeration of particles within the filter media. Some of these dendritic fibres themselves start to act as filter fibres, increasing the effective packing density over time. The process of dendrite formation is extremely complex and difficult to predict, but the averaged effects on filtration performance, analogous to increasing fibre diameter and packing density in the early stages, with cake formation and terminal clogging ultimately, are more accessible.

With respect to the effects of dendrites a number of assumptions have been made in the model. They are (a) the particle aerosol will homogeneously load the filter, (b) all

collected particles form dendrites but not all dendrites will be involved in further collection, and (c) the ones involved in further collection will be determined empirically once the model has been developed.

In a similar manner to Eqs.(4) and (5), the collection efficiency of dendrites is given for time increments $k \geq 1$, $1 \leq J \leq N$, $1 \leq l \leq n_r$

$$E_{p,J,l,l+k} = 1 - \exp\left(\frac{-4 \cdot \alpha_{p,J,l+k} \cdot \eta_{p,J,l,l+k} \cdot Z_J}{\pi \cdot (1 - \alpha - \alpha_{p,J,l+k}) \overline{d_{p,J,l+k}}}\right) \tag{6}$$

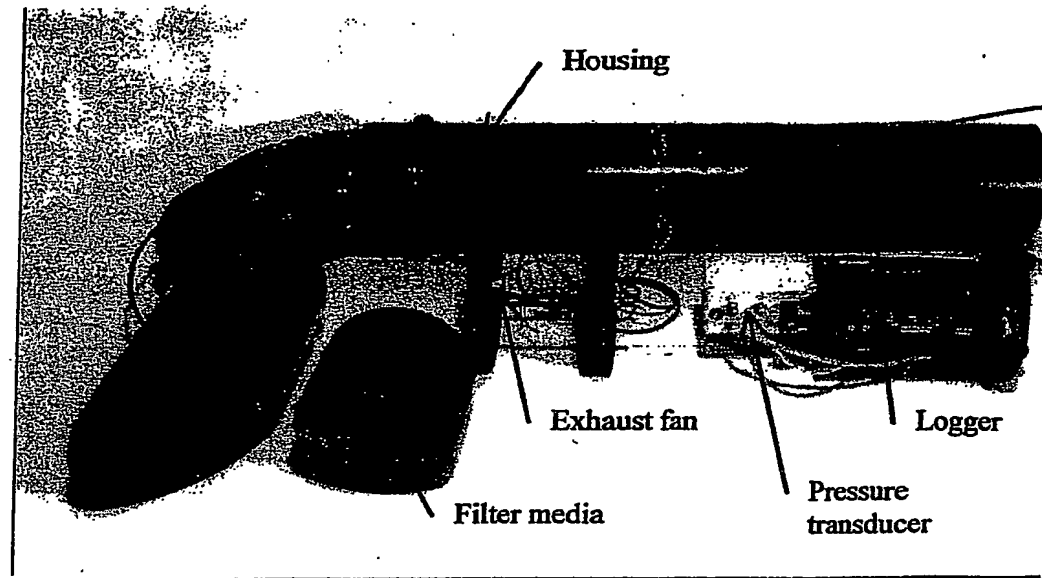$$\eta_{p,J,l,l+k} = \eta_{p,d,l} + \eta_{p,in,l} + \eta_{p,im,l} \tag{7}$$

Where d_p is the mean diameter of dendrites, obtained from:

$$\overline{d_{p,J,l+k}} = \frac{\overline{d_{p,J,l+k-1}} \cdot \alpha_{p,J,l+k-1} \cdot \rho_p \cdot Z_J \cdot S + \sum_{l=1}^{n_r}(m_{f,J,l,l+k} + m_{p,J,l,l+k}) d_{p,l}}{\alpha_{p,J,l+k-1} \cdot \rho_p \cdot Z_J \cdot S + \sum_{l=1}^{n_r}(m_{f,J,l,l+k} + m_{p,J,l,l+k})} \tag{8}$$

Field test rig:

Two field test rigs, to facilitate calibration of the filtration model, have been completed. They are used to measure the cumulative pressure drop across dynamic insulation / filter media as particulate matter accumulates over a period 6 - 12 months for known variable loading.

A pre-assembly picture of one of the test rigs is shown below, comprising a durable pipe housing with shielded intake and radial exhaust vents, filter media holder, axial extract fan, and low pressure transducer / data logger module.

Figure 1.2 Propreitary field test rig being used for model calibration
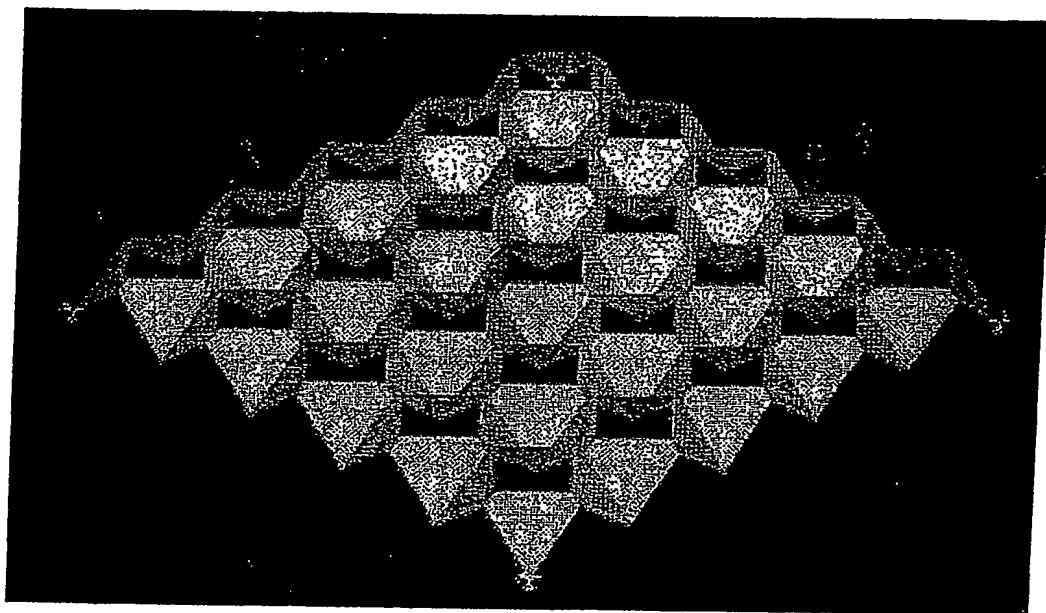
The insulation / filter media employed in the tests is VG4LWRO 4" oiled graduated glass, supplied by McLeod Russell. It has the following specifications - weight dry: 500-540 g/m^2; weight oiled: 640 g/m^2; fibre diameter: 25-30 microns; free thickness: 101.6mm ± 6.3mm Compressed thickness 54mm ±3; The oil is chlorinated paraffin. Packing fraction was estimated for lab-measured permeance values.

1.3 The PM$_{10}$ Cladding Panel

For dynamic insulation to function optimally it is necessary for incoming ventilation air to flow uniformly through the largest possible area of a building's or structure's breathing envelope, but for infiltration or leakage flows through gaps, cracks, leaky doors and windows, etc., to be reduced as much as possible. Fibre-based media are not self-supporting, making their precise placement and long-term stability and fixity within the cladding panel or system problematic. In addition it is difficult to achieve a seamless, airtight joint between such materials and the rigid encapsulating structures

used in a cladding panel or system. Finally, occlusion of airflow through the inlet and outlet faces of fibre-based dynamic insulation media, for example by external bracing, would reduce the effective face area and degrade performance.
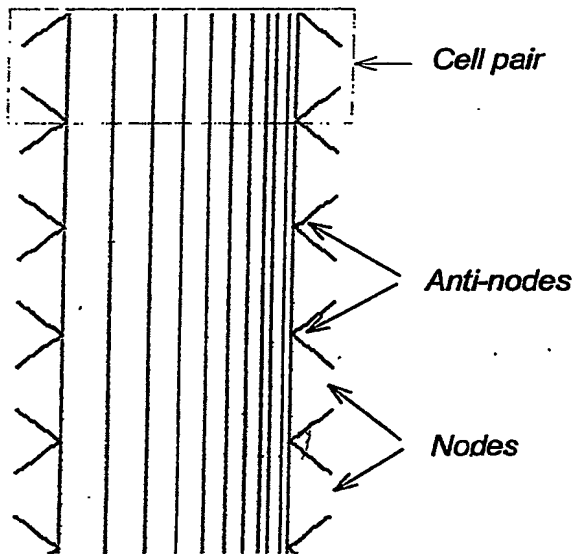
The authors have developed a simple yet elegant solution to these and several other problems.   In this solution two rigid multi-function panels, each made up of a *diamond lattice* of outward-facing open (i.e., truncated, or otherwise permeable) nodes to admit the airflow and inward-facing pointed anti-nodes to grip into the fibre media, support and encapsulate the media. The lattice dimensions are scalable and material choice is wide, but the geometry is proprietary and very specific, with a representative partial sample of a single panel depicted in figure 1.3 below   .

Figure 1.3 Multi-function panel geometry - 25-cell square sample

The encapsulation of dynamic insulation as described results in a *core dynamic insulation element* that may be used for a multitude of external wall, roof or floor types forming parts of the envelope of a breathing building or structure. With reference to the sectional schematic in figure 1.4, it can be seen that the truncated

nodes form a mirrored pair of aligned multi-function panels permit airflow and support the encapsulated dynamic insulation without occluding the faces of the media. The shape of each cell pair is important, acting as a simple diffusion - contraction unit that helps to achieve uniformity of airflow through cell and media. Such cell pairs form a repeating structure that, together with the finite value of permeability of the media ensures excellent uniformity of flow through the core element, irrespective of what inlet / outlet conditions are imposed.

Figure 1.4 Section through core dynamic insulation element

Thus, where the air is introduced into the wall panel and / or where it is extracted from the panel would, in practice, have little or no detrimental effect on flow uniformity through the media. This uniquely desirable behaviour is demonstrated in the CFD results presented in figures 1.5 and 1.6 , obtained for a rainscreen-cladding panel incorporating a dynamic insulation core element. Figure 1.5 shows outdoor air being drawn into the cladding panel through a vent at the base of the rainscreen as the building is depressurised. This air queues up in the gap between the rainscreen and core cladding element (the inlet plenum), flows uniformly through the dynamic insulation media and thereafter spills into the space behind the internal wall skin (the

outlet plenum) before being dumped, preheated and filtered, through a vent at ceiling height into the room, or air handling system.
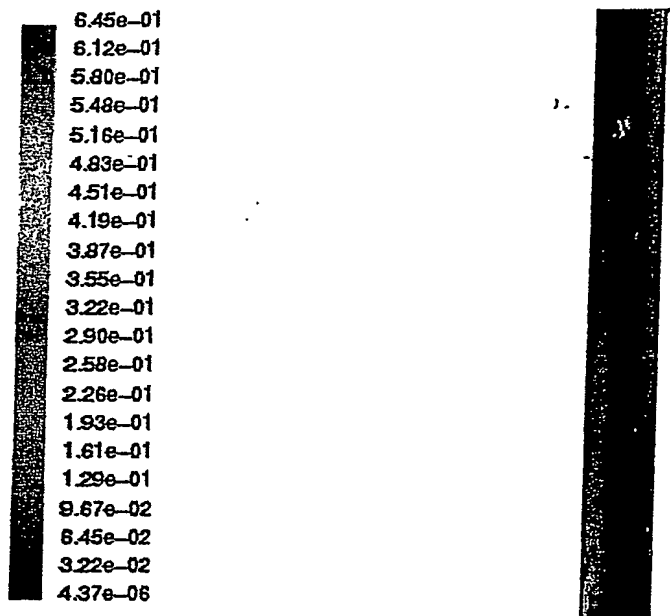
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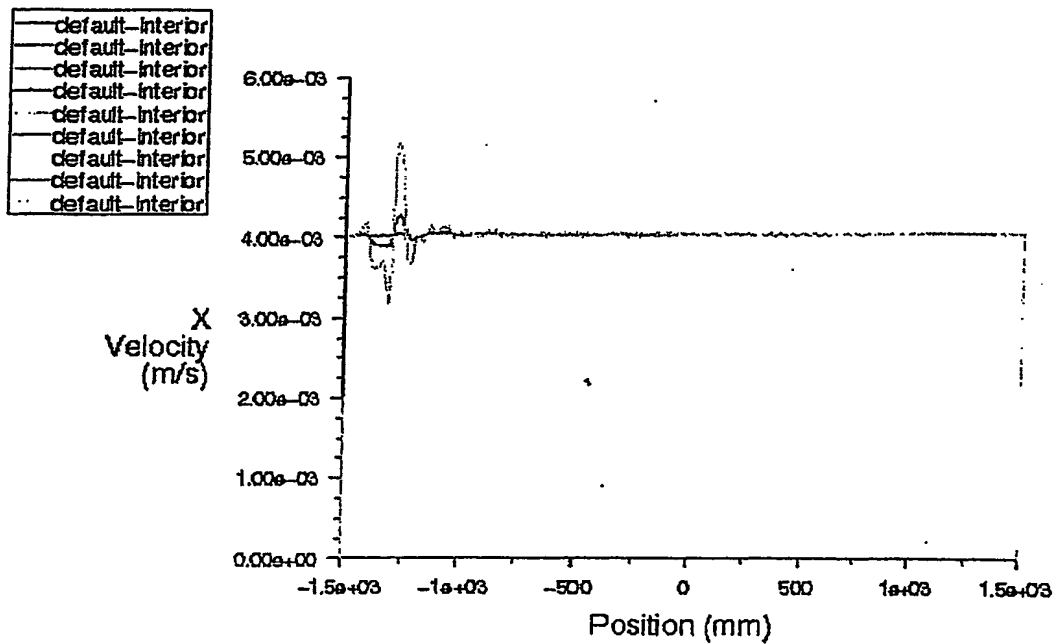**Figure 1.5** *Velocity distribution through a 3m breathing cladding panel D300-40*

Figure 1.6 *Mid-plane velocity profile through dynamic insulation media*

The very flat (less than 2% variation) velocity profile through the encapsulated

dynamic insulation media seen in figure 1.6, for this particular panel arrangement, was

little changed when mid-height vents, directly opposing vents, and numerous other

variations of inlet / outlet vent location, inlet / outlet plenum size, etc., were examined.

Use of the core dynamic insulation element thus ensures optimum performance

irrespective of where the inlet and outlet vents are located. In all of the cases

examined all of the breathing wall area was effectively utilised, freeing the building

designer of all of the constraints and limitations previously associated with this form

of construction.

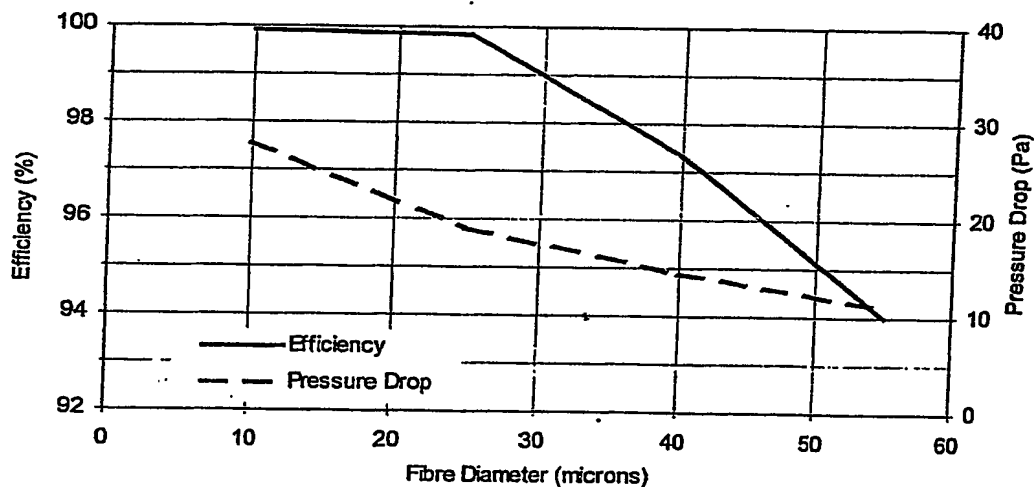## 1.4 Air Filtration Design and Indoor Air Handling Solutions

The uncalibrated model was used to provide preliminary answers to the crucial

questions of filtration efficiency over time and lifetime before clogging. A simple

scenario, built around a small office suite in a polluted environment and its ventilation

requirements, was developed and used to generate a set of results from the model. The

results show the model behaving in a predictable manner, and very reassuring in terms

of the filtration efficiency achievable and panel life before clogging occur.

To generate the conditions required for ventilation air, typical office suite conditions

provided a convenient template. CIBSE guideline ' indicate that 16 litres of air has

to be provided per person per second in a smoking (i.e., worst case) environment.

The test conditions are for 5 people in an office demanding a volumetric fresh air flow

rate of 80 l/s through 10 m^2 of breathing wall area (the ventilation source). The

resulting airflow velocity through the wall thus works out as 0.008 m/s. The definition

of clogging was chosen as that point where the pressure drop required to provide

acceptable levels of ventilation air exceeded 40 Pa (beyond which opening / closing

doors becomes difficult). The pollution imposed was for Marylebone Road in London, where the average yearly PM_{10} level is 48 μg/m3, most of which is from incomplete combustion in motor vehicle engines. The density of the pollutant was assumed to be 1850 kg.m-3, at the top end of the pollutant spectrum. Temperature was taken to be 291K.
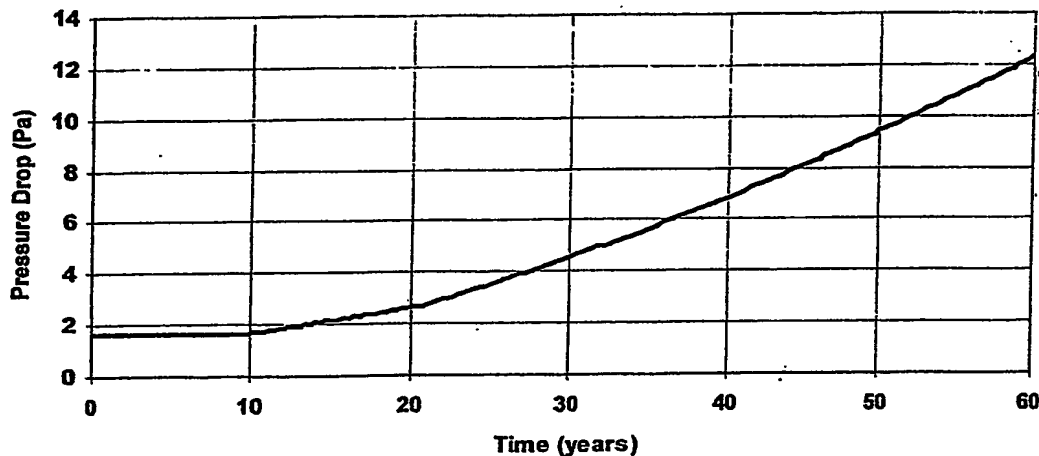
The trial, only part of which is reported here, is a 3-variable, 4-level full factorial design with no replication, resulting in a total of 64 sets of results. The effects of varying fibre diameter and packing fraction through depth were investigated for a graded insulation layer of thickness 100 mm, divided into 5 progressively denser slices of equal depth. The variables examined were fibre diameter (10 - 55 μ), initial packing fraction (0.008 - 0.011), and the corresponding packing fraction gradients (0.0035 - 0.002 per slice). For each time increment, the efficiency of each slice at filtering each particle diameter of pollutant was calculated. That pollutant not collected in the first slice was transferred to the next slice, etc. In this way, the efficiency of the entire layer was calculated.

Figure 1.7 The effect of fibre diameter on pressure drop and efficiency

Space restrictions only permit presentation of the results of greatest interest, namely the minimum efficiency of particulate filtration during the first time increment for fresh media, and the maximum pressure drop across the insulation media over time. As the fibre diameter reduces in size so the efficiency of collection and the pressure drop increase, as shown in the preceding figure. . The initial particle filtration efficiency for 10 and 25 micron fibres was thus greater than 99.8%, with corresponding pressure drops of 25 and 19 Pa at 60 years respectively.
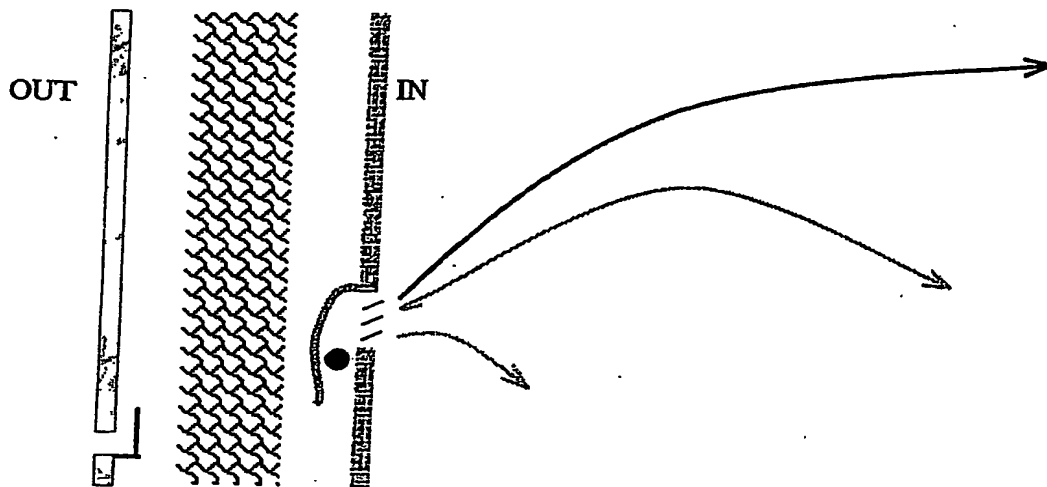
The evolution of pressure drop with time during a 60 year period is shown in the figure below for an insulation / filter layer of 55 micron fibre diameter, initial packing fraction of 0.011 and incremental increase of 0.002 per slice. As fibre diameter decreases the pressure drop increases, in the same way that reducing the packing fraction increases pressure drop, all other variables being the same.

Figure 1.8 Evolution of pressure drop with time

Although energy was not considered explicitly in the office suite example, the significant savings (up to 30% reduction in energy use through dynamic U-value reduction, decreasing slightly as depressurisation level increases over time with clogging) outlined in section 1.1 and elsewhere are achievable.

With respect to in-room conditions for breathing buildings, air drawn in at extremely low velocities through the panel must be moved and distributed throughout the office space to ensure adequate ventilation. One method of doing this could be to pass the induced air over a LPHW heating pipe coil, preferably embedded within the panel (or via grills mounted on window sills) and served from circulating pipe mains, with a central boiler providing the primary heat source. The incoming air would acquire buoyancy as it is heated, enhancing both the flow of air through the panel and its circulation within the room in the manner of a conventional radiator. Although details of implementation may vary from building to building, typical deployment of this simple yet well-established design solution is depicted in figure 1.9 below.

OUT   IN

Figure 1.9 Single pipe run round system plus central extract

Other more elaborate solution could include zone void-pack with re-circulation and heat recovery, centralized air-handling and distribution, etc., depending on the level of control desired. The crucial point is this: Breathing buildings fitted with the core dynamic insulation element described in this paper can work well, and deliver their full benefits, using today's tried and tested HVAC equipment and design methods.

It is clear that the built environment has a significant role to play in reducing carbon emissions. A number of alternative approaches to achieving this aim exist, and examples abound for the implementation of natural ventilation, reduced losses through building fabric, control of solar gains, increased air tightness, and so on.

A revolutionary cladding technology that is applicable to both new-build and refurbishment projects is described herein. The technology brings significant benefits such as reduced operational energy use, reduced embodied energy use through the elimination of supply ducting, reduced maintenance costs through provision of filtration for life, the building as a clean-up technology, and the potential of a building that is guaranteed to protect its users against external pollutants and other hazards indefinitely.

The design and performance of a dynamically insulated wall cladding panel have been presented and discussed. The initial design criteria were to create a panel that would facilitate fixing the fibre-based insulation material, edge sealing of the panel and airflow control. These criteria were met through development of a novel eggcrate-like structure to support and encapsulate insulation media and aid airflow uniformity through the full wall area.

CFD simulation confirms that excellent airflow uniformity through a dynamically insulated wall panel could be achieved using this approach, irrespective of where the inlet or outlet to the panel is located. The effect of this is threefold. Firstly, the entire wall area is used as a contra flow heat exchanger. This maximises heat exchange between the wall and the incoming ventilation air. Secondly, it maximises the area of

insulant used to filter the incoming ventilation air. Thirdly, it frees the designer to locate the fresh air inlet into the room (or air-handling unit) anywhere on the wall face.

A 1-d PM10 filtration model has been described which was used to design an insulation material which would have filtration performance of >99.9% on day 1 of operation. The model calculated the rise in pressure drop over a 60-year period.

The model predicted that the pressure drop would increase from 1.8 to 12.2 Pa over this time period at an air flow of 0.008 m/s. Test rigs have been constructed which will allow the model to be calibrated.

Claims:-

1.   A cladding material comprising:-
5   a. intermediate layer having filtering characteristics;
            a support element;
wherein the support element comprises a plurality of nodes interconnected in a planar lattice arrangement, said nodes each having a pointed face, the pointed faces of the lattice arrangement being arranged to project in substantially the
10 same direction for engagement with the intermediate layer in use.

2.   A cladding material according to claim 1, wherein the cladding material comprises a support element provided on each side of an intermediate layer.

15 3.   A cladding material according to claim 1 or 2, wherein the nodes are interconnected at their peripheries to define spaces therebetween.

4.   A cladding material according to any preceding claim, wherein the pointed face of each node comprises an apex projecting from a base, the nodes
20 being interconnected at or adjacent their bases.

5.   A cladding material according to any preceding claim, wherein each node has a pyramidal form.

25 6.   A cladding material according to any preceding claim; wherein the intermediate layer has a graduated filtering profile.

7.   A cladding material according to claim 6, wherein the filtering characteristics of the intermediate layer are such as to trap relatively large
30 particles towards an outer end thereof and to trap relatively smaller particles towards the inner end thereof.

8.   A cladding material according to any preceding claim, wherein the

intermediate layer has thermal and/or sound insulating properties.

9. A cladding material according to any preceding claim, wherein intermediate layer comprises one or more of:- mineral wool, wet-blown cellulose
5 and glass wool.

10. A cladding material according to any preceding claim, wherein the intermediate layer is provided in the form of one or more of:- membranes, fibres, pulp or cellular based (foam or sponge) materials, or modified aerated
10 concrete. :

11. A cladding material according to any preceding claim, wherein the cladding material comprises filter materials for one or more of:- particulate emissions, gas pollutants, chemical agents and biological agents.
15

12. A cladding material according to any preceding claim, wherein the cladding material is provided in the form of panel units.

13. A cladding material according to claim 12, wherein the panel units are
20 provided in modular format.

14. A cladding material according to any preceding claim, wherein the intermediate layer is formed of a plurality of one or more separate filter layers, of different filtering characteristics.
25

15. A cladding material according to claim 14, wherein each filter layer of the intermediate layer is selected to extract a specified range of particle sizes, gaseous pollutants, chemical pollutants, and/or biological agents.

30 16. A cladding material according to claim 15, wherein the separate filter layers of the intermediate layer together define substantially the complete filter spectrum of particulate and other pollution.

17.   A cladding material according to any claim 14, wherein the or each filter layer of the intermediate layer is independently replaceable.

18.   A cladding material according to claim 17, wherein the or each filter layer of the intermediate layer comprises one or more disposable filter elements.

19.   A cladding material according to any preceding claim, wherein the support element is pressed from a single sheet.

20.   A cladding material according to any one of claims 1 to 18, wherein the support element is moulded from a plastics material.

21.   A cladding material according to any preceding claim, wherein the support element is formed of fire retardant materials.

22.   A cladding material according to any preceding claim, wherein a support element unit is formed by a plurality of nodes interconnected around a space, such that in use with the nodes engaging with the intermediate layer, the unit presents an opening of expanding volume onto the intermediate layer.

23.   A cladding material substantially as hereinbefore described with reference to the accompanying drawings.

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